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An ASABE Meeting Presentation

Paper Number: 1009142

Field Evaluations of Application Techniques and Equipment for Wheat Disease Management

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Written for presentation at the
2010 ASABE Annual International Meeting
Sponsored by ASABE
David L. Lawrence Convention Center
Pittsburgh, Pennsylvania
June 20 – June 23, 2010

Abstract. *New variants of wheat pathogens are emerging in various countries for which there is no known resistance. The current movement of these pathogens suggests that their incursion into the US is imminent. The objective of this work was to identify effective application parameters to apply fungicides for protecting against wheat head scab and stem rust infection. Field trials were designed to evaluate the effect of spray volume, spray quality, and air assistance on the fate of spray on sections of a wheat plant most susceptible to infection. Following application of a fluorescent tracer tank mix, plant samples were collected from each of ten plants in each replicate for each treatment. Plant sections sampled included Heads, Flag Leaf, Flag Leaf +1, and the Stem between the Head and Flag Leaf +1. There were no significant differences between treatments in the amount of spray on the stem sections. Significant differences between treatments were observed for the amount of spray found on Head and Leaf sections. Directing the spray and air stream 30° forward increased deposits of Medium spray quality droplets on the Head sections but reduced deposits on the more horizontal Flag leaves. Spray coverage measured on targets with a vertical and cylindrical shape to simulate the wheat head target also increased when the air/spray stream was directed 30° forward compared to a vertical delivery. These results demonstrate that different application parameters may be required depending on the specific section of the wheat plant that requires protection.*

Keywords. Stem rust, droplet size, air-assisted, fluorescent tracer, wheat.

Introduction

The ability to provide protection across the wheat plant is important because different infections may occur on different parts of the plant canopy depending on the pathogen. Fusarium Head Blight results from fungal infection of the wheat head in the early stages of flower development. Wheat Stem Rust is caused by airborne movement of a pathogen and primarily causes infection on stems but can also cause infection on leaves. Leaf Rust is caused by a fungus that primarily infects leaves. New disease strains for which no natural disease resistance is available require use of protectant fungicides to manage the diseases.

Looking to optimize spray quality and spray orientation guidelines for cereal disease management, Wolf and Caldwell (2004) showed that coarse sprays from air induction nozzles and double nozzle arrangements (one forward and one back) increased deposition on vertical and horizontal artificial targets representing targets in a cereal canopy. Wolf and Caldwell also demonstrated that increasing the angle of spray delivery between double nozzles increased spray deposits. Halley et al. (2008) used a combination of treated wheat heads and water sensitive paper to compare various application parameters for treating wheat heads. The authors found that 93.5 L/ha applications produced higher fungicide deposits on the wheat heads than either applications made at 187or 46.8 L/ha. Halley et al. also found that spray quality between Fine and Medium classifications produced higher deposits and higher spray coverage.

In an aerial application study, Fritz et al. (2006) demonstrated through spray deposit and spray coverage results that a combination of low application volume (19 or 47 L/ha) and large droplet size (VMD=350 µm) produced the greatest deposits on wheat heads. North Dakota State University Extension (Halley et al., 2010) recommends orienting the air/spray discharge on an air-assist sprayer to be 30° down from horizontal and forward in the direction of travel. The recommended air stream velocity is 22 m/s. NDSU also recommends using nozzles that produce a Fine or Medium spray quality delivering spray at 93.5 L/ha to maximize head deposits.

The objective of this research was to determine the influence of spray quality, spray volume, and air-assisted delivery on wheat canopy penetration and deposition which could aid in selection of efficacious means for delivering fungicides to different parts of wheat canopy for effective management of diseases that may predominantly reside in hard-to-reach parts of the canopy. Evaluation of tracer residue on head, stem, and leaf tissue was used to characterize treatment effectiveness to provide a true representation of where spray was deposited on different portions of a plant canopy.

Materials and Methods

Field trials were conducted on Ohio State University's research farms around Wooster, Ohio, in June 1 and 4, 2009. Field plots were arranged in a Completely Randomized Block Design with treatments randomly assigned to plots within the 24 plot trial. Each plot was approximately 22.9 m long and 3.7 m wide. A 3.3 m drive row was cut out of the field along the side of each plot. Wheat was planted in drilled rows with 18 cm row spacing. Applications were made when the wheat reached the 10.5 Feeke's reproductive growth stage (Large, 1954) which is the most likely time for head scab infection.

Leaf Area Index (LAI) was measured to characterize the density of the canopy at the time of applications. LAI of the wheat canopy was determined using an LAI-2000 plant canopy analyzer (LI-COR®, Inc., Lincoln, Nebraska) with two sensor modes. Three points in each plot were randomly selected for the LAI measurement. The sky was fully covered by clouds at the moment of measurement. The LAI sensor was also calibrated under fully-cloudy conditions. The average LAI across all 24 plots was 3.48.

Table 1 shows the six spray treatments evaluated including travel speeds, application rate, and spray droplet measurements. The Jacto Model Advance 3000 pull type agricultural sprayer (Jacto, Pompeia, SP Brazil) with an 18.3 m long air sleeve along the entire length of the boom was used to make all applications. The outlet of the air sleeve was positioned behind the nozzles. Air speeds are the center of the outlet as measured with a handheld air velocity probe (Model 8386A VelociCalc Plus Air Velocity Meter, TSI Incorporated, Shoreview, MN) is shown in Table 1. All nozzles used on the Jacto sprayer were manufactured by Spraying Systems Co. (Wheaton, IL). Manufacturer's reported spray quality data were used to select nozzles that would provide Medium (XR11004 and XR8003) and Fine (XR110025) spray quality as described by ASAE nozzle classification standard 327.2 (2004). Nozzle spacing on the boom was 50 cm for all treatments. Nozzle height was set at 33 cm above the canopy prior to each application. It was felt that this boom height provided the best opportunity to provide a relatively uniform spray distribution at all sampling positions in the canopy. All treatments applied the same spray mixture containing water and Brilliant Sulfaflavine (BSF) (MP Biomedicals, Inc., Aurora, OH) at a concentration of 2 g/L.

Droplet sizes for the treatments listed in Table 1 were measured with the Oxford Lasers VisiSizer particle/droplet image analysis system (Oxford Shire, UK). Droplet size distributions were determined 33 cm below the nozzle orifice across the centerline of the spray pattern width. A minimum 10,000 droplets were counted at each sampling position for the droplet size distribution analysis. Droplet size measurements were made without the aid of any air-assisted delivery.

Table 1. Wheat Stem Rust treatment descriptions.

Treatment	Air Outlet Speed (m/s)	Application Rate (L/ha)	Nozzle Pressure (kPa)	Travel Speed (km/h)	Droplet size (µm)		
					$D_{V.1}$	$D_{V.5}$	$D_{V.9}$
(1) XR11004	N/A[1]	140	207	11.3	85.7	224.5	439.2
(2) XR11004	18	140	248	11.3	85.7	224.5	439.2
(3) XR110025	18	94	248	11.3	83.9	159.0	312.5
(4) XR110025	34	94	248	11.3	83.9	159.0	312.5
(5) XR8003	18	94	172	11.3	105.7	263.6	465.7
(6) XR110025, Boom angle- 30° Forward	18	94	248	11.3	83.9	159.0	312.5

[1]No air-assisted delivery

The wheat canopy was allowed to dry for at least 10 minutes prior to collecting target samples. For plant material samples, field staff selected two sets of five plants (primary tillers) from between 9 and 15 m inside the plot along a diagonal across the plot for a total of ten plants. Staff cut each stalk of wheat at ground level. After each group of five plants were collected, staff moved outside of the plot to cut each plant and divide them up by Head, Flag Leaf (FG), Flag Leaf +1 (FG+1), and Stem sections. Figure 1 illustrates how each plant was divided. The Flag Leaf was the upper most leaf on the plant. Flag Leaf +1 was the first leaf below the Flag Leaf. All cut sections were stored in 125 ml glass bottles. Bottles were capped after sections from each of the five plants were collected. The remaining wheat sections were discarded.

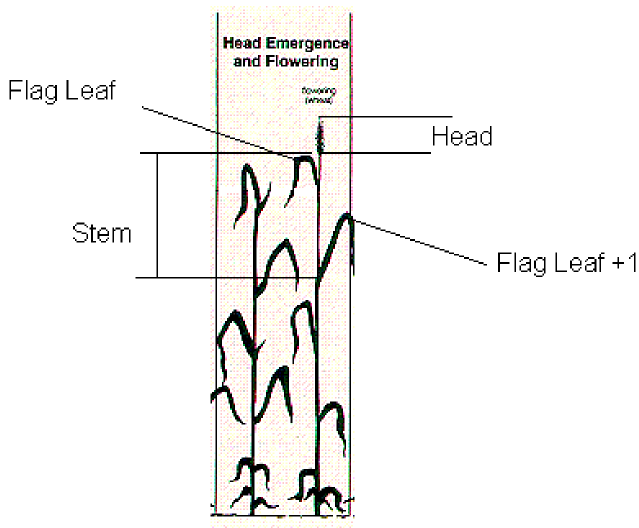

Figure 1. Wheat plant section identification.

Plant sections were washed by adding 40 mL of purified water to each sample bottle. After the water was added the lid was placed back on and the jar was shaken by hand for 20 seconds. After shaking, 4 mL of the rinse solution was placed into a cuvette, and the sample was put in a fluorometer to determine the fluorescent intensity. It was read against a standard calibration curve to determine the mass of dye in each sample. Peak fluorescent intensity with a luminescence spectrometer (model LS 50B, Perkin-Elmer, Ltd., Beaconsfield, U.K.) at an excitation wavelength of 460 nm. If a sample concentration fell above the calibration range, it was further diluted and measured again. Quantification of dye deposition was achieved using a standard concentration curve prepared with serially diluted samples of known concentration. The mass of tracer found on the targets was converted to spray volume using the concentration of tracer in the tank mix because not all treatments applied the same rate of tank mix.

Water sensitive paper (WSP) targets (52 x 76 mm) (Syngenta Crop 132 Protection AG, Basle, Switzerland) were positioned within the canopy to measure vertical and horizontal spray deposit characteristics. Figure 2 shows how WSP targets were positioned within the wheat canopy. WSP targets were supported on three different rods located approximately 2 m from the edge of each plot along the drive row and at 9, 12, and 15 m from the starting edge of each plot. The Vertical WSP targets were wrapped around wooden dowels (10 cm x 1.0 cm diameter) with the overlapped point facing down the row toward the end point of each plot. The Vertical target was positioned at approximately the height of the head. Horizontal WSP targets were held with electrical clips fastened to the support rod. A pair of WSP targets was located on opposite sides of the support rod at each sampling height. The long axis of each Top Canopy target was oriented parallel to the row direction. The height of the Top Canopy WSP targets was approximately the height of the flag leaves. The Middle Canopy WSP targets were positioned approximately 30 cm below the Top Canopy WSP targets with the long axis of each target perpendicular to the row direction. After the WSP targets had dried following each treatment, they were collected and stored in paper bags.

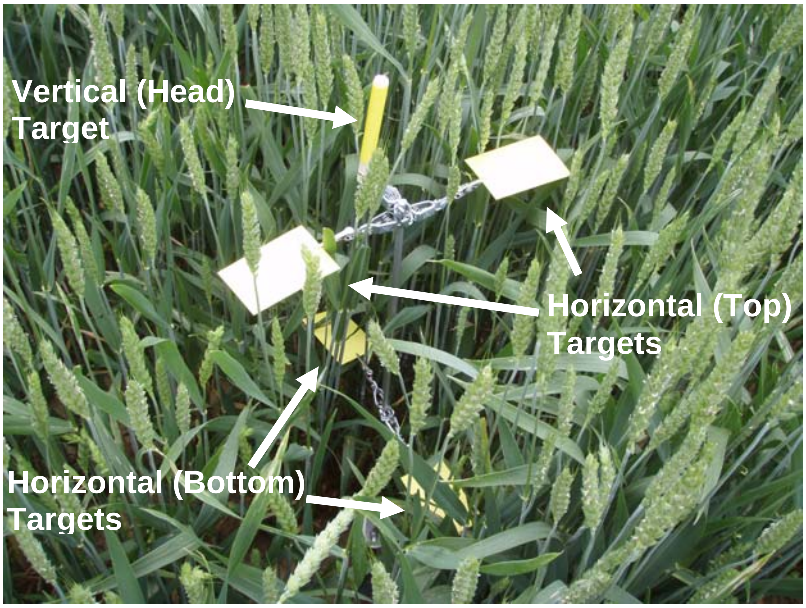

Figure 2. Position of five Water Sensitive Paper targets within canopy.

Spray deposit characteristics on WSP was measured with a portable scanning system including a handheld business card scanner (NeatReceipts, NEAT Business Cards color scanner, Philadelphia, PA), a desktop computer, and a custom-designed program "DepositScan" (http://www.ars.usda.gov/mwa/wooster/atru/depositscan). The resolution of the scanned images was 600 dpi. Vertical (Head) WSP targets were removed and flattened before being scanned. Only areas on the WSP that was exposed to spray were used for spray deposit characteristics measurements. After spray deposit images on the WSP were scanned the program reported the size of each spot, spot size distributions ($D_{V.1}$, $D_{V.5}$, and $D_{V.9}$), total number of spots, and percentage area covered by the spots.

Spray deposit results were analyzed using a mixed model in SAS (SAS, 1990) where Plots and Subsamples were considered to be random effects and Treatment was the only fixed effect. The subsample groups consisted of five composited plant parts for a total of 10 wheat plants per plot. Four locations on the wheat plants were examined separately: Head, Flag Leaf (FG), Flag Leaf +1 (FG+1) and Stem. A Levene's homogeneity of variance test was performed on the raw data to determine whether any variance stabilizing transformations of the data were necessary. The FG data required a square root transformation to stabilize the variance. Single-factor mixed effects ANOVAs (analysis of variance) with subsampling were conducted on each plant section. Pairwise differences among treatments were examined using the differences of least squares means.

The means of the two targets for Top and Middle canopies were used in a mixed model SAS for statistical evaluation of the measurements made on the WSP targets. A Levene's homogeneity of variance test was performed on the raw data to determine whether any variance stabilizing transformations of the data were necessary. Single-factor mixed effects ANOVAs (analysis of variance) with subsampling were conducted on each plant section. Pairwise differences among treatments were examined using the differences of least squares means at $p \leq .05$ with a Bonferroni adjustment.

Results and Discussion

Table 2 shows the mean volume of spray tank mix deposited on plant material in the 2009 field trials. Significant treatment differences from ANOVA tests for spray deposits were found for Head, FG, and FG+1 plant sections. Spray volume was not necessarily a significant variable on the wheat heads. Even though Treatments 1 and 2 delivered 50% more spray than the other treatments, they only produced significantly higher deposits than Treatment 4 operating at the highest air outlet speed while applying smaller droplets with the Fine spray quality nozzle (XR110025). Air-assisted delivery did not produced significantly higher deposits between Treatments 1 and 2 at 140 L/ha. There was no significant difference in spray deposits found on the wheat heads between the high air outlet speed treatment (4) and medium speed (3) treatment applied at 10 L/ha. There were no significant differences in deposits on wheat heads between those treatments made at 10 L/ha but the highest air speed treatment (4) produced the lowest mean deposit on the wheat heads. Angling the air/spray stream forward did not produce significant differences in head deposits (3 vs. 6). In addition, spray quality did not produce significant differences in spray deposits on the heads at the 94 L/ha application rate (3 vs. 5).

Air outlet speed settings did not significantly change spray deposits on the FG plant sections at either of the application rates tested (1 vs. 2 and 3 vs. 4). Among the treatments made at 94 L/ha, treatment 5 with the Medium spray quality XR8003 produced the highest mean deposits on the FG plant sections but it was only significantly different from treatment 4 made at the highest air outlet speed setting. Treatment 3 with the vertical orientation of the air/spray stream did not produce significantly different deposits on the FG plant sections from treatment 6 with the 30° delivery angle. Higher application rate did not necessarily produce higher deposits on the FG plant sections. There was no significant difference between treatments 2 and 5 which used nozzles that produce similar spray quality (Medium) but were made at different application rates. As found on the Head sections, the highest air outlet speed (34 m/s) produced the lowest mean spray deposits on the FG plant sections but the mean was not significantly different from treatments 3 and 6 made at the lower air outlet speed settings (18 m/s).

The 140 L/ha treatments (1 and 2) produced significantly higher deposits lower in the canopy on the FG+1 plant sections than all other treatments except for treatment 5 made at 94 L/ha using a Medium quality spray nozzle (XR8003). Among the 94 L/ha treatments, treatment 5 made using a Medium quality spray nozzle produced significantly higher deposits on the FG+1 plant sections treated using the 30° air/spray angle (6) but was not different from the treatments made using the Fine quality (XR110025) nozzle (3 and 4). There was no significant difference in the spray deposits found on FG+1 plant sections between treatments made at the same application rate but using nozzles producing different spray quality (3 vs. 5).

Table 2. Mean spray deposit (μL/5 plants) across sprayer treatments found on sections from five plants and standard deviation.

Treatment	Head		Flag Leaf		Flag Leaf +1		Stem	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	31.65 ab[1]	7.80	49.00 ab	14.30	33.25 a	11.91	14.17	5.52
2	38.69 a	12.55	49.87 a	18.28	27.16 ab	7.96	19.40	13.48
3	29.90 abc	7.49	36.33 bc	13.07	18.79 cd	5.14	16.35	7.87
4	22.57 c	4.77	24.45 c	3.79	18.93 cd	3.59	7.78	1.82
5	25.33 bc	4.36	41.22 ab	11.00	22.32 bc	6.46	11.55	5.53
6	31.18 abc	12.82	26.72 c	12.50	14.63 d	4.32	11.98	7.09

[1]Treatment mean spray deposits within a column (location) followed by the same letter(s) are not significantly different based on differences of least squares means at p≤.05.

Analysis of stem deposits did not show significant differences between treatments (table 2). Treatment 2 making the 140 L/ha application using the lower air outlet speed setting (18 m/s) produced the highest mean deposits on the Stem sections. The high air outlet speed setting (34 m/s) produced the lowest mean deposit on the Stem sections.

The spray coverage measured on WSP targets in the three different sections of the canopy are shown in Table 3. Spray coverage was similar on all Head targets but treatment 5 made using the Medium quality spray nozzle (XR8003) produced the lowest mean coverage. High spray volume (140 L/ha) tended to produce higher spray coverage on the Head targets but not significantly higher coverage than most of the 94 L/ha treatments. Angling the air/spray stream forward didn't significantly change spray deposits on the Head targets (3 vs. 6). In general, air outlet speed did not significantly influence the amount of spray coverage measured on Head targets (1 vs. 2 and 3 vs. 4).

Treatment 4 using the high air outlet speed setting (34 m/s) produced significantly higher spray coverage (Table 3) on the horizontal Top Canopy targets than the lower air outlet speed setting (18 m/s) air speed setting (3). The higher volume (140 L/ha) application rates produced significantly higher spray coverage on the Top Canopy targets than treatments 3 and 5 made at 94 L/ha using Fine and Medium spray quality nozzles respectively at the lower air speed setting (18 m/s). There was no significant difference in spray coverage between the Fine and Medium spray quality treatments made at 94 L/ha using the lower air speed setting (3 vs. 5). Treatment 4 using the high air outlet speed setting (34 m/s) produced higher spray coverage than treatment 3 using the same equipment settings except for the lower air outlet speed setting (18 m/s). Angling the air/spray stream 30° forward did not significantly change deposits on the Top Canopy targets compared to the vertical orientation of spray delivery (3 vs. 6).

As shown in Table 3, the higher spray volume treatments (1 and 2) tended to produce the highest spray coverage on the horizontal Middle Canopy targets but not significantly different from treatments 3 and 4 made at 94 L/ha. In particular, treatment 2 made at 140 L/ha using Medium spray quality nozzles (XR11004) produced significantly higher spray coverage than treatment 5 made at 94 L/ha also using a Medium spray quality nozzle (XR8003). There were no significant differences between the 94 L/ha treatments (3-6) although treatment 6 made with the 30° air spray angle orientation produced the lowest mean spray deposit.

Table 3. Mean percent spray coverage across sprayer treatments and standard deviation.

Treatment	Head		Top Canopy		Middle Canopy	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	14.44 a[1]	4.65	30.42 a	3.63	18.67 a	3.65
2	14.77 a	2.47	29.11 a	3.27	16.98 a	3.27
3	11.82 ab	2.17	22.34 bc	4.42	13.16 ab	4.25
4	11.52 ab	2.21	29.73 a	4.59	15.62 ab	2.19
5	8.55 b	2.50	20.38 c	2.73	11.12 b	2.97
6	13.93 a	4.17	27.02 ab	5.56	10.72 b	3.46

[1]Treatment means within a location column followed by the same letter(s) are not significantly different based on differences of least squares means at $p<.05$ using a Bonferroni adjustment.

Table 4 shows that air outlet speed did not significantly affect droplet density on the vertical Head targets (1 vs. 2 and 3 vs. 4). Treatment 3 applied at 94 L/ha using the Fine spray quality XR110025 nozzle produced significantly higher droplet density on the horizontal WSP targets than treatments 1 and 5 applied using Medium spray quality nozzles (XR11004 and XR8003 nozzles respectively). While angling the air/spray stream 30° forward reduced the droplet density on the Head targets compared to the vertical orientation delivery, it was not significantly different. There was no significant difference in droplet density on vertical Head targets between the higher volume (140 L/ha) and lower volume (94 L/ha) treatments made using Medium spray quality nozzles but the higher spray volume did produce a higher mean droplet density (2 vs.5).

Similar to the Head WSP targets, treatment 3 using the Fine spray quality nozzle applied at 94 L/ha produced the highest mean droplet density (110.88 spots/cm^2) on the horizontal Top Canopy targets and treatment 5 using the Medium spray quality nozzle applied at 94 L/ha produced the lowest mean droplet density (65.34 spots/cm^2) at the upper most elevation. Droplet density was significantly higher for the Fine spray quality nozzle (XR110025) treatment compared to the application made using the Medium spray quality nozzle (XR8003) (3 vs. 5). Similar to the vertical Head targets, spray volume did not produce significantly different droplet densities on the horizontal Top Canopy targets (2 vs. 5).

Different from the horizontal Top Canopy WSP targets, treatment 5 with the higher air outlet setting produced the highest mean droplet density (91.28 spots/cm^2) on Middle Canopy WSP targets. However, the droplet density produced by treatment 5 was only significantly different from droplet densities produced by treatments 1 and 5 which were both made using Medium spray quality nozzles. Mean droplet density on the horizontal Middle Canopy targets was not significantly different between treatments applied at 94 and 140 L/ha using Medium spray quality nozzles (2 vs. 5). Spray delivery angle did not significant affect droplet density on the Middle Canopy WSP targets (3 vs. 6). Use of air assistance in treatment 2 at 140 L/ha did not produce significantly higher spray deposits than treatment 1 (no air assistance). As found on the Head and Top Canopy WSP targets, spray quality has a significant effect on droplet density at the Middle Canopy elevation. The Fine spray quality nozzle (XR110025) produced a higher droplet density than the Medium spray quality nozzle (XR8003) when applying the same application rate (3 vs. 5).

Table 4. Mean droplet density (spots/cm^2) across sprayer treatments and standard deviation.

Treatment	Head		Top Canopy		Middle Canopy	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	69.59 b[1]	27.04	86.05 abc	12.72	61.82 bc	10.22
2	88.18 ab	25.97	80.72 bc	11.63	71.96 abc	17.40
3	114.29 a	32.72	110.88 a	21.57	85.67 ab	23.82
4	82.25 ab	28.98	86.08 abc	17.75	91.28 a	24.87
5	61.24 b	13.77	65.34 c	10.37	50.06 c	14.22
6	87.21 ab	20.93	103.01 ab	21.40	74.24 abc	19.14

[1]Treatment means within a location column followed by the same letter(s) are not significantly different based on differences of least squares means at $p<.05$ using a Bonferroni adjustment.

Conclusion

Good spray delivery is important when relying on protectant fungicides to help manage wheat diseases that may infect the head, leaves, or stem sections. Different pathogens tend to cause infection on different plant parts. Differences in application methods were identified by studying spray deposits on plant sections and deposit characteristics on water sensitive paper (WSP). In general, the overall differences in the performance parameters measured were small between the two spray application rates tested (140 vs. 94 L/ha). The highest possible air outlet speed available on the Jacto sprayer (34 m/s) produced few advantages over lower outlet air speeds. Penetration to the middle of the canopy was generally not a problem for the treatments using no air-assisted delivery or the lower air outlet speed setting (18 m/s). The high air outlet speed setting did produce lower deposits on the Head and Stem sections. Angling the air/spray stream 30º forward produced higher deposits and coverage on the Head targets but the results were not significantly different from the air/spray stream with the vertical orientation. Greater spray angles may be needed to significantly improve application performance but may reduce penetration into the canopy. Applications made with the Medium spray quality nozzle (XR8003) using the lower air outlet speed tended to produce lower spray deposits than the Fine spray quality nozzle (XR110025) when used to deliver the same flow rate. In particular the Medium spray quality nozzle treatment tended to produce smaller droplet density across all targets and lower spray coverage which could reduce disease control effectiveness.

Acknowledgements

The authors would like to acknowledge the support of The Ohio State University, OARDC Agronomy Farm for providing field space for conducting these trials. In addition, the authors want to acknowledge the particular contributions by Andy Doklovic for securing the research space and preparing the field equipment, Keith Williams for supporting meteorological data collection, Leslie Morris and Jenny Barnett for organizing the supplies and evaluating samples, and Matt Tignor for analyzing all of the water sensitive paper samples and summarizing the results. The authors are also very appreciative of the support of USDA-ARS, MWA statistician Deb Palmquist for performing the statistical analysis of the results.

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